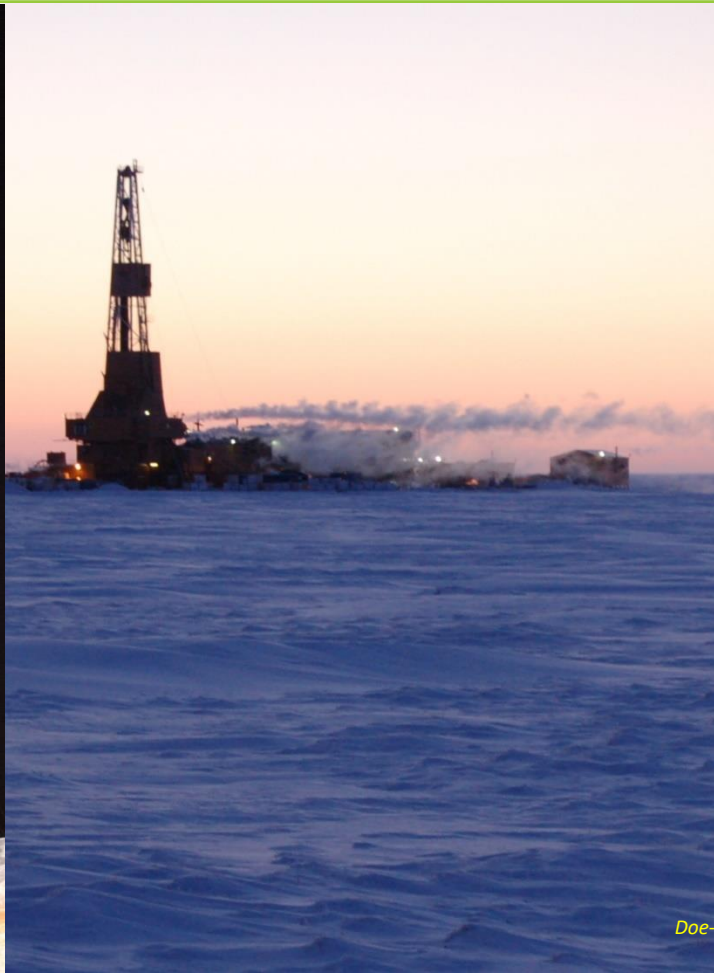


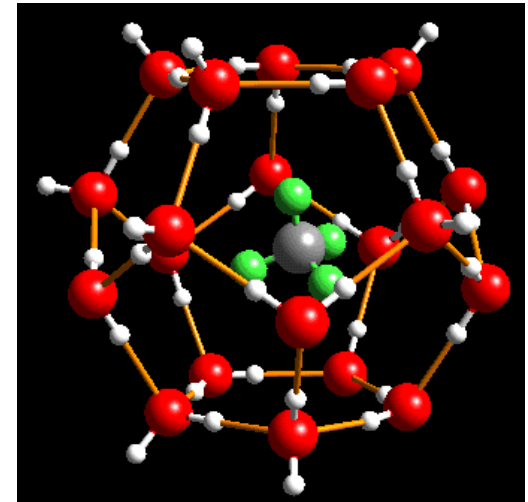
An Overview of US DOE Gas Hydrate Research and Development

Midstream Workshop, Houston TX



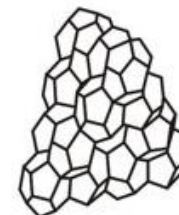
What are Gas Hydrates?

- Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules
 - One volume hydrate typically equivalent to 160-180 volumes methane gas
- Natural gas hydrate (NGH) is an enormous global storehouse of organic carbon.
- Methane is less carbon intensive fuel than other hydrocarbon, 44% less CO₂ than coal, 29% less than oil, per unit energy release.
- Methane is 20x stronger global warming gas than CO₂



Structure I

**Methane, ethane,
carbon dioxide....**



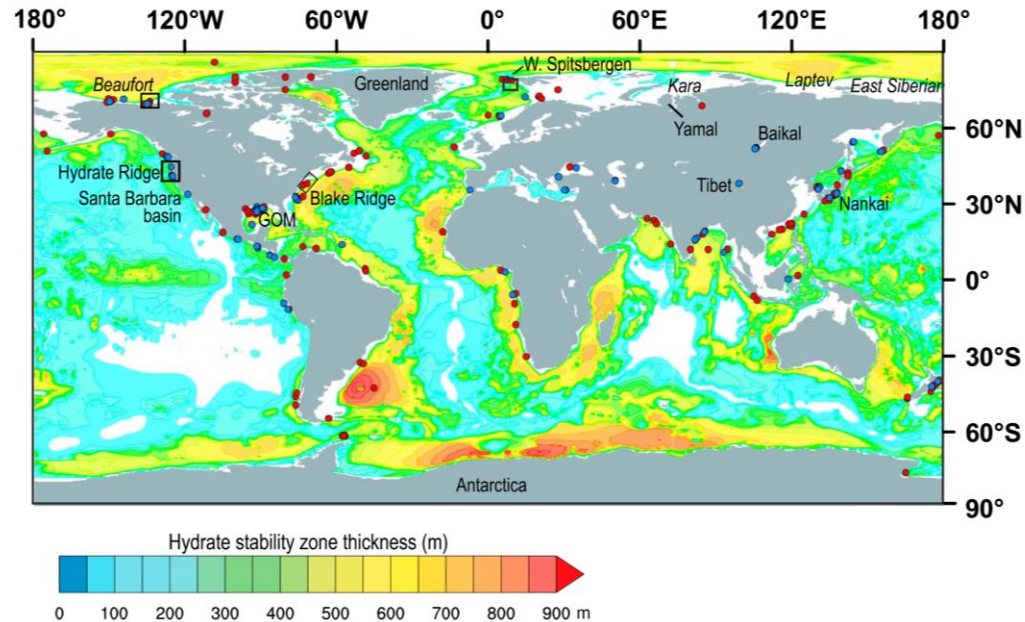
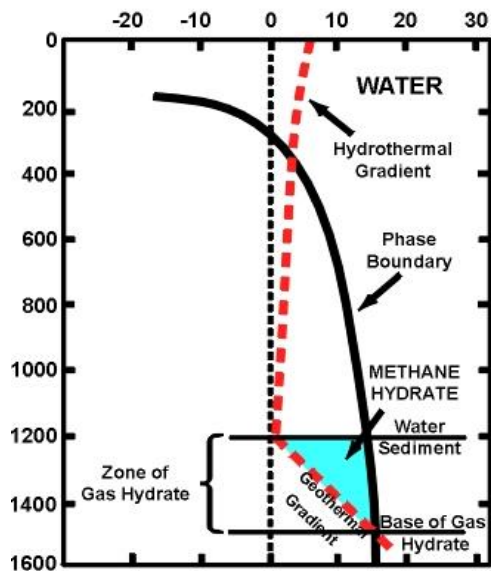
Structure II

**Propane, iso-butane,
natural gas....**

Gas Hydrate Stability Conditions

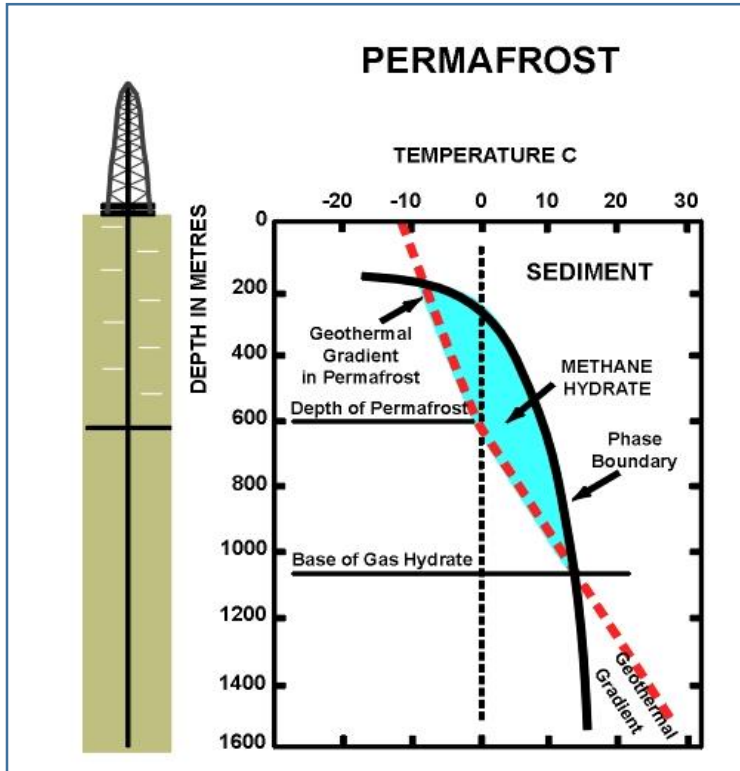
MARINE

TEMPERATURE C



Ruppel and Kessler, 2017

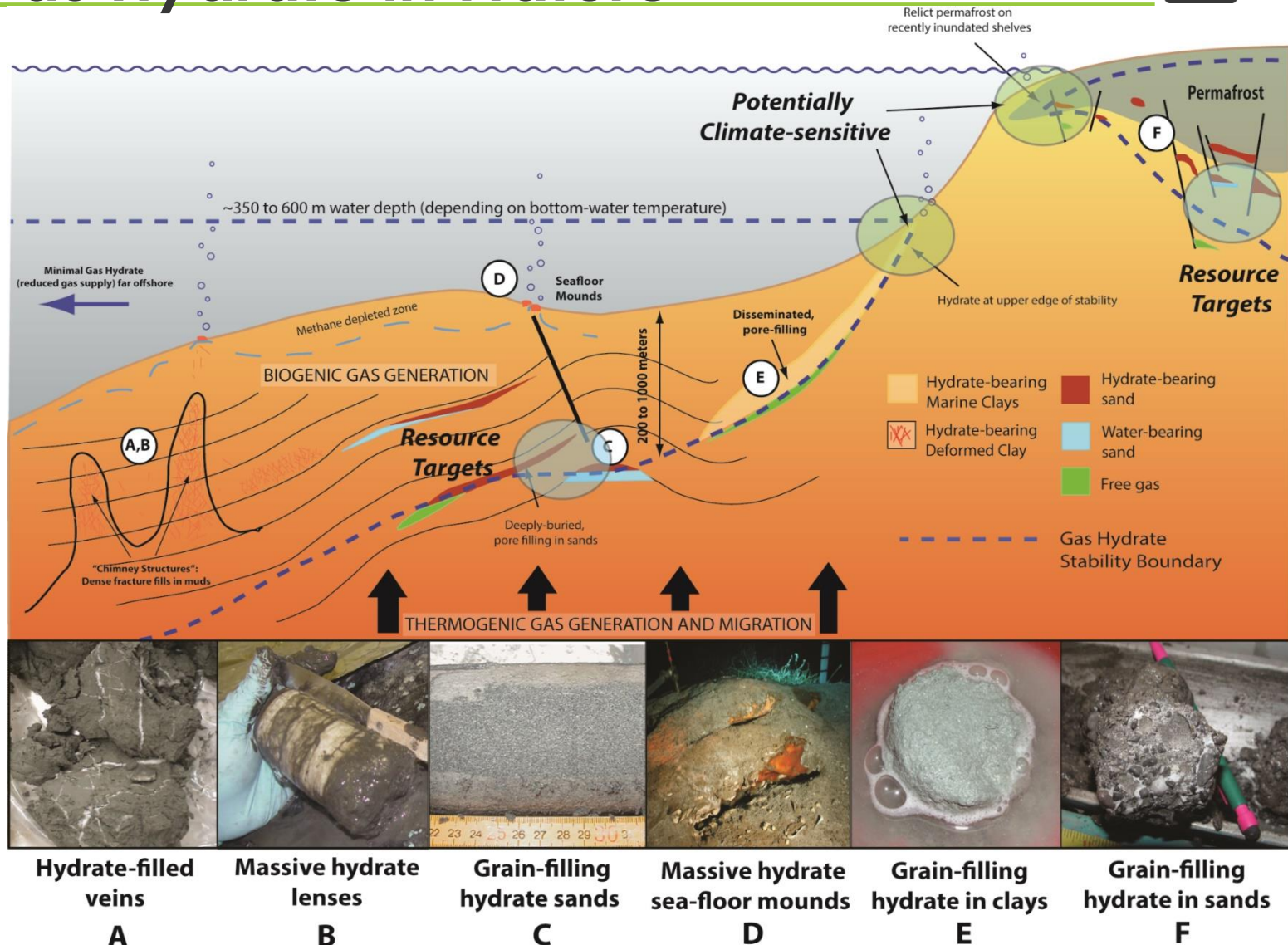
Gas Hydrate Stability Conditions



Arctic Permafrost Gas
Hydrate Stability Conditions

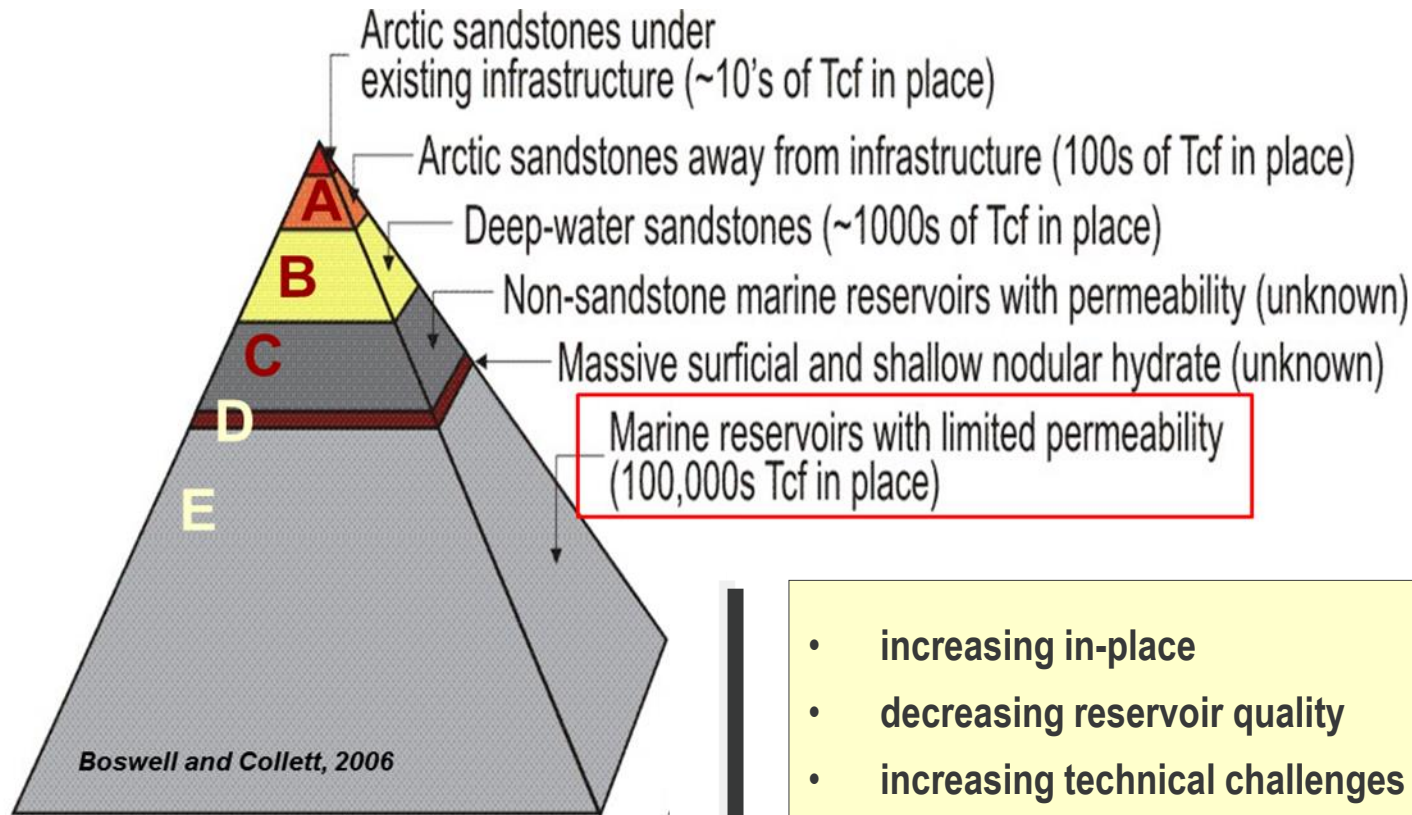
*Max and Lowrie, 1992
Collett et al., 2009*

Gas Hydrate in Nature



The Gas Hydrates Resource Pyramid

Distribution of huge in-place resource



Data Sources

A: Collett, 1993; Collett, 1995

B: MMS, 2008

C: Unassessed (India, Korea expeditions)

D: Unassessed

E: Collett, 1995

- increasing in-place
- decreasing reservoir quality
- increasing technical challenges
- decreasing % recoverable

GH-Saturated conglomerate – NW Canada (Mallik)



GH-saturated turbidite – Nankai trough



GH-saturated fractured clays – Bay of Bengal



Massive GH seafloor mound – Gulf of Mexico



Alaska North Slope GH Assessment

- **Discrete Accumulations**
 - Petroleum System
 - The USGS method for “conventional” reservoirs
 - Three AUs; with size range and accumulations numbers for each
- **~85 TCF gas in place**
- **Technically Recoverable**
- **Existing Technology**
 - High ultimate tech recoverability

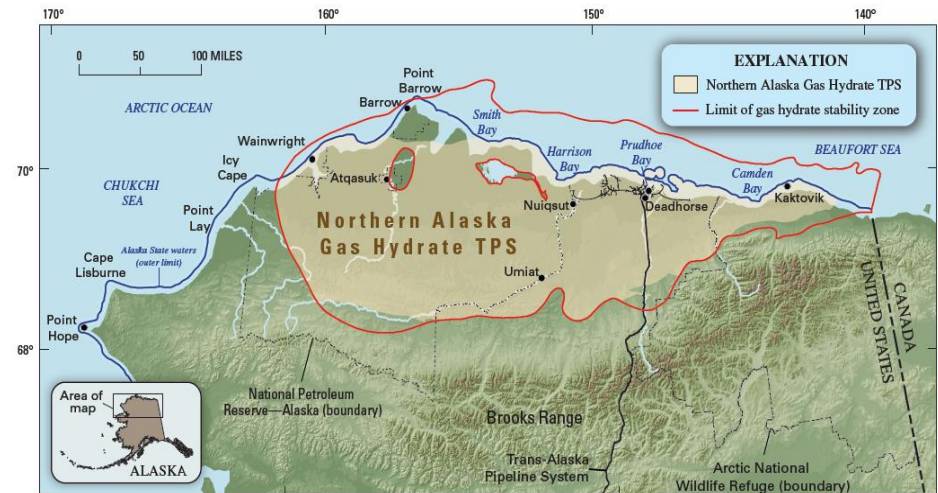


Table 1. Alaska North Slope–Gas hydrate assessment results.

[BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive, assuming perfect positive correlations. NGL, natural gas liquids; TPS, total petroleum system; AU, assessment unit.]

Total Petroleum System and Assessment Unit	Field Type	Total Undiscovered Resources							
		Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean
Northern Alaska Gas Hydrate TPS									
Sagavanirktok Formation Gas Hydrate AU	Gas	6,285	19,490	37,791	20,567	0	0	0	0
Tuluvak-Schrader Bluff-Prince Creek Formations Gas Hydrate AU	Gas	8,173	26,532	51,814	28,003	0	0	0	0
Nanushuk Formation Gas Hydrate AU	Gas	10,775	35,008	68,226	36,857	0	0	0	0
Total Undiscovered Resources		25,233	81,030	157,831	85,427	0	0	0	0

In-Place Gas Hydrate in US OCS

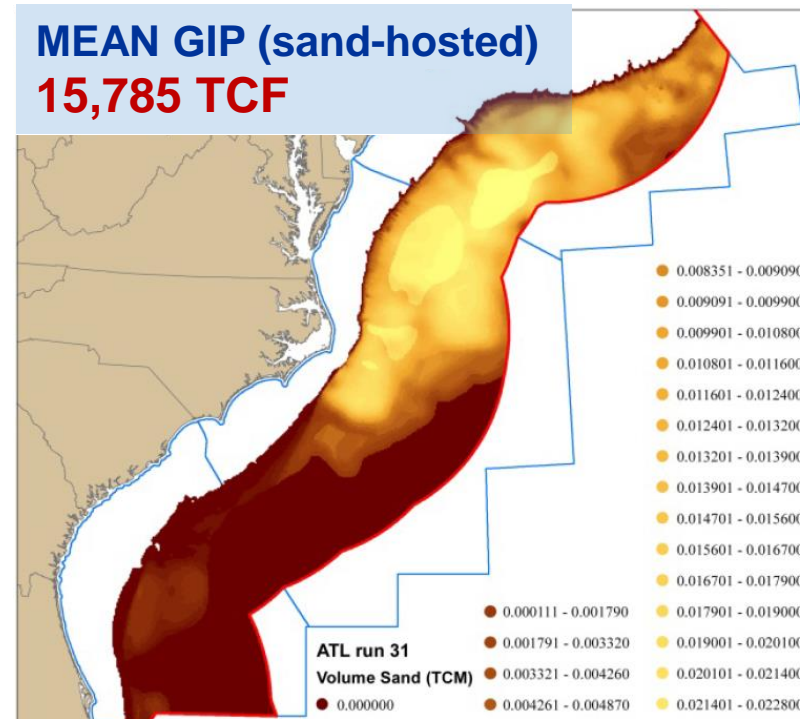
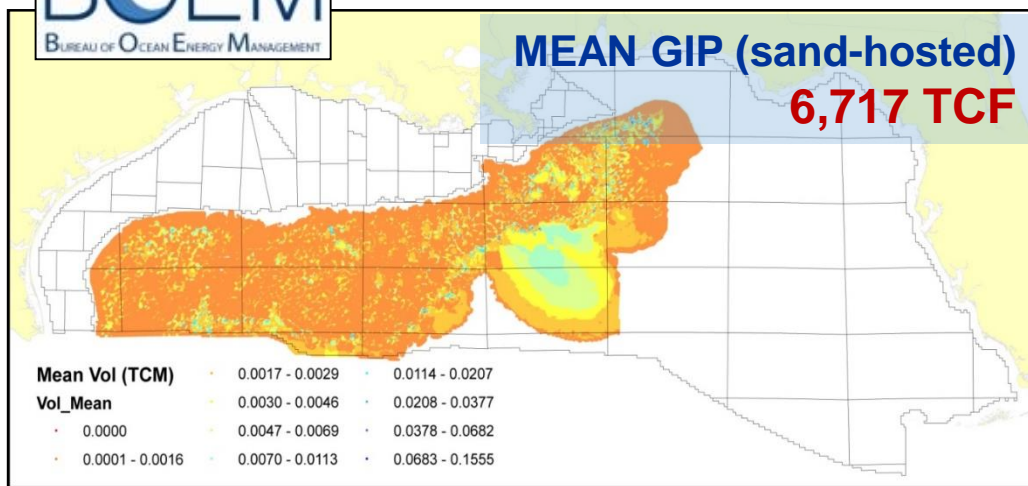
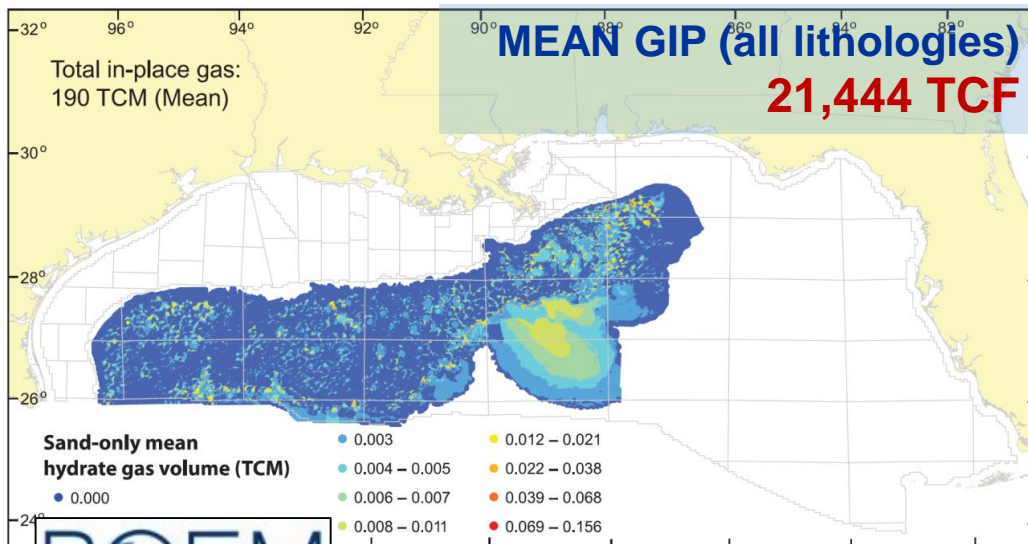


Table 1. BOEM in-place gas hydrate resource volumes for the Atlantic, Pacific, and Gulf of Mexico Outer Continental Shelf. Units are trillion cubic feet; $1 \times 10^{12} \text{ ft}^3$. Resource volumes have not been subject to geologic risk.

Region	In-Place Gas Hydrate Resources		
	Gas (Tcft)		
	95%	Mean	5%
Atlantic OCS	2,056	21,702	52,401
Pacific OCS	2,209	8,192	16,846
Gulf of Mexico OCS	11,112	21,444	34,423

US National Gas Hydrate Program

Program Mission

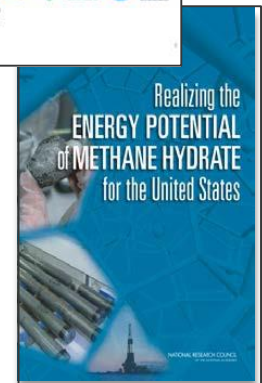
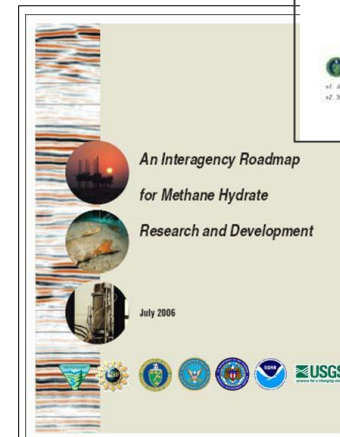
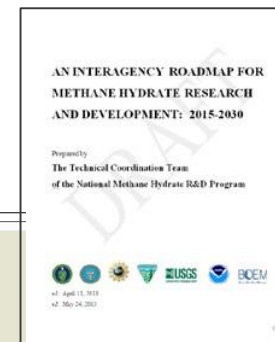
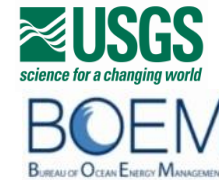
- Determine the potential for methane hydrates as an energy source,
- Identify environmental impacts associated with production, and its role in the global climate cycle.
- Interagency & International
- Gas Hydrate In Nature
- Science And Technology
- Outreach & Education
- Emphasis On Research In The Field

Near-term Goals (2020)

- Demonstrate long-term Technical Recoverability (Alaska)
- Confirm Gulf of Mexico Resource Assessment
- Continue International Collaborations

Long-term Goals (2025)

- Confirm scale of US resource base (+ Atlantic)
- Demonstrate Production Approach (Alaska + International)
- Develop consensus view on GH/Climate linkages via field programs + modeling



DOE – NETL GH Program

Major Program Areas

Marine Resource Characterization / Confirmation

- Marine drilling and coring programs throughout US OCS
- Focus on major drilling/logging/coring field effort in GoM with UT

Production Science

- Evaluating behavior of GH in response to induced change
- Focus on establishment of long term GH production test in AK

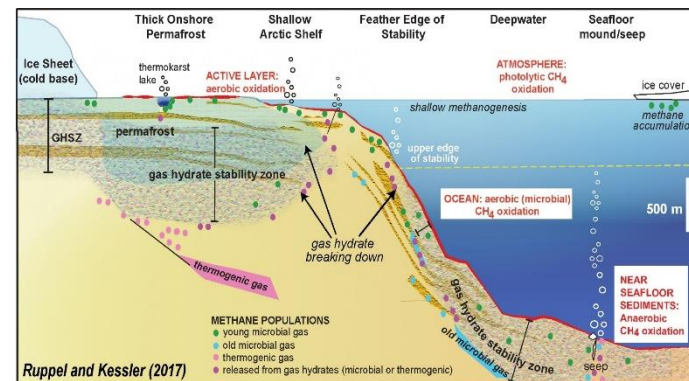
Fundamental Science

- Fundamental scientific efforts in geophysics, experimentation, simulation, tool development and other areas to support scientific understanding necessary for resource characterization, exploration and production of GH
- Conducted with Academia, National Labs and other Federal Agencies

GH Role in the Natural Environment

- Investigate, through the acquisition of field data and development of predictive models, the nature of hydrate response to warming climates and implications for ocean and atmospheric chemistry.
- Conducted with Academia, National Labs and other Federal Agencies

International Collaborations

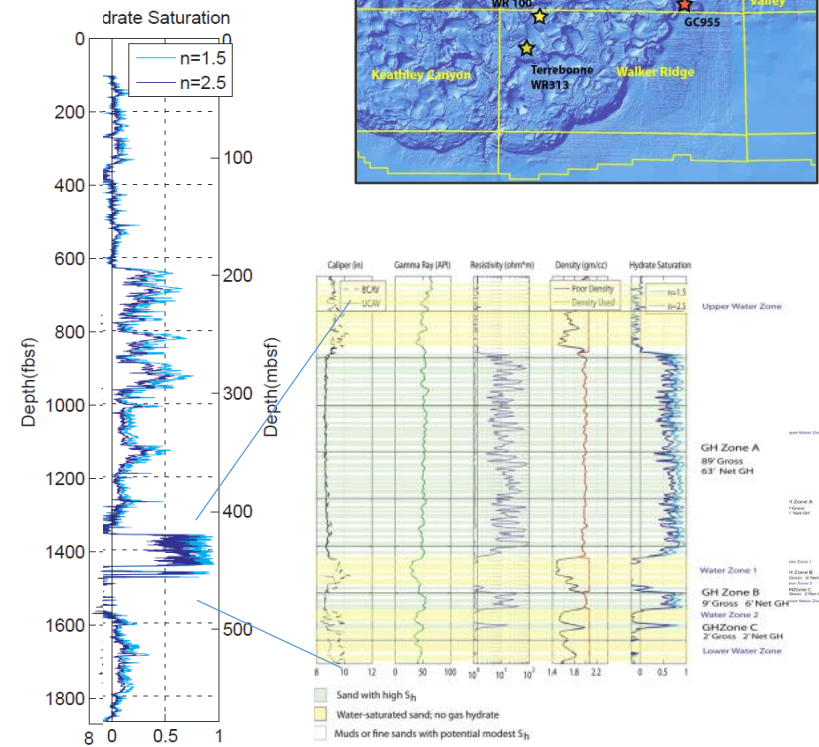
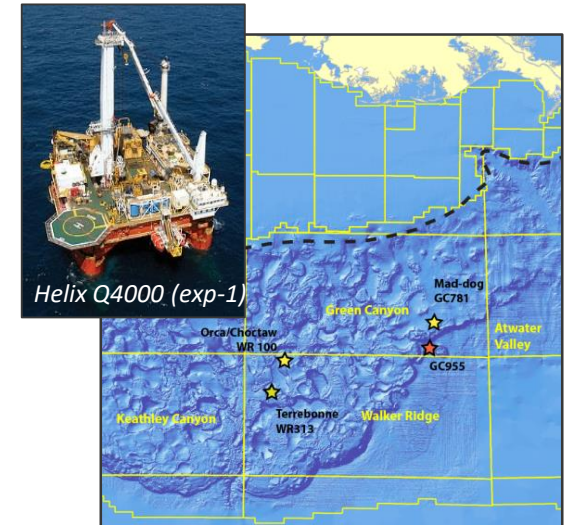


GOM² Expedition: UT Austin

Pressure-coring at known sites and exploration of high-value new sites

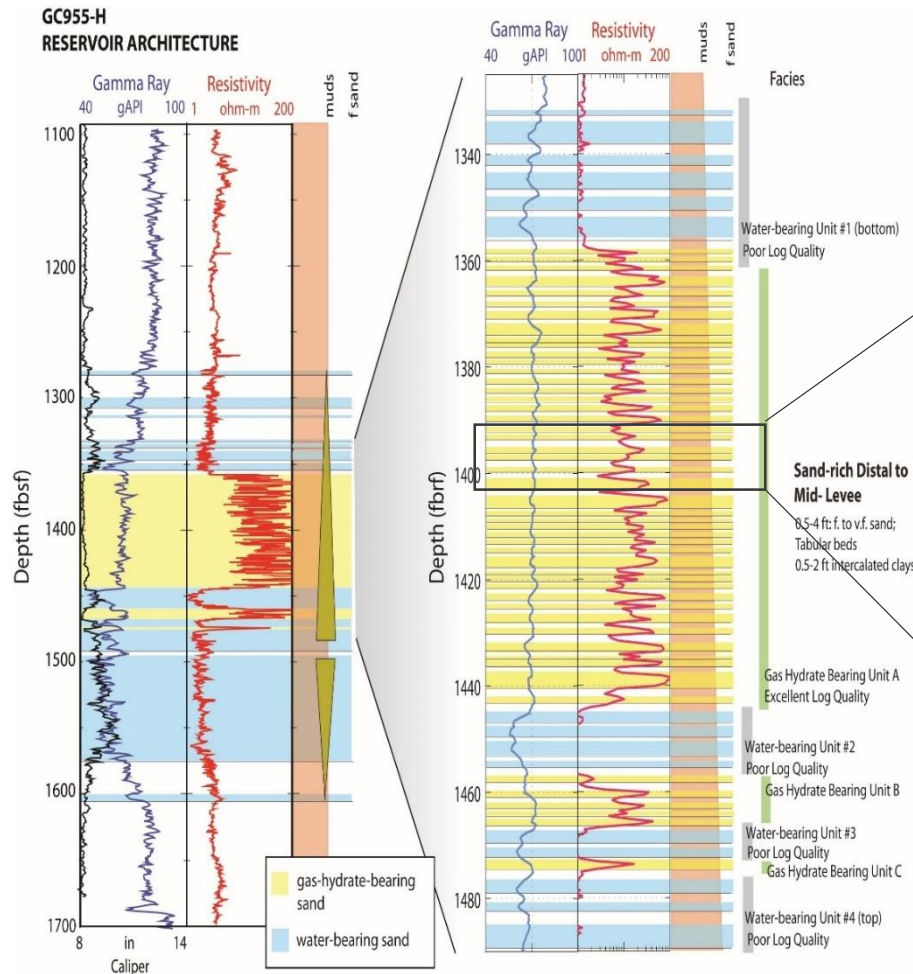
Expedition – 1 (Completed Spring 2017)

- Single site, two-hole, test of pressure corer, core transfer and core analysis. 20 deployments.
- Full science program (UT, DOE-NETL, USGS, Geotek)
- Two bit configurations (PCTB) tested: (PCTB-CS: 6% Rec., PCTB-FB: New tool design: 75% Rec)
- All 20 sample transfer vessels filled with very high-quality hydrate-bearing sand samples
- **NO SAFETY INCIDENTS, NO WELL CONTROL INCIDENTS, ON TIME, ON BUDGET**
- Core to undergo analysis by multiple research groups: UT, USGS, NETL, AIST



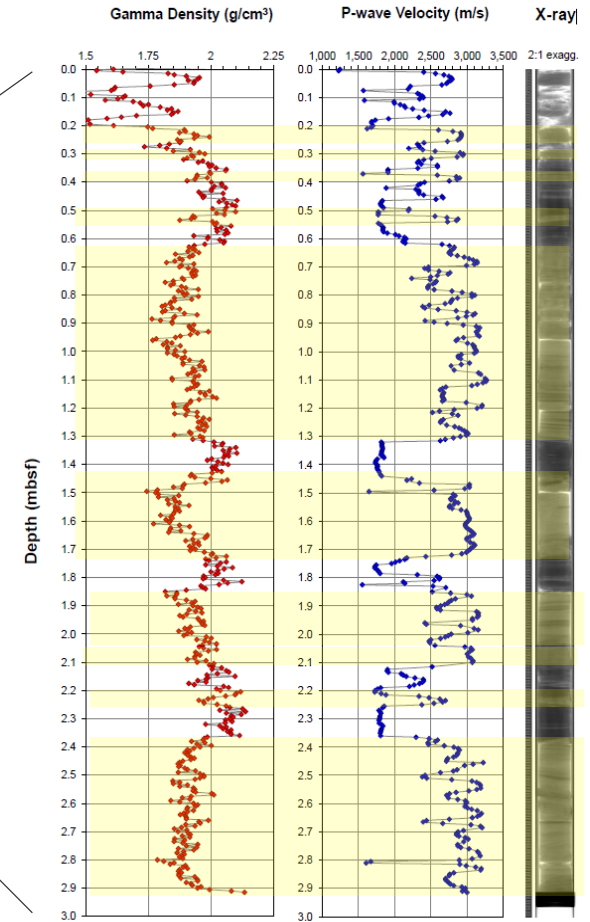
Green Canyon 955

Reservoir Architecture confirmed at Core Scale



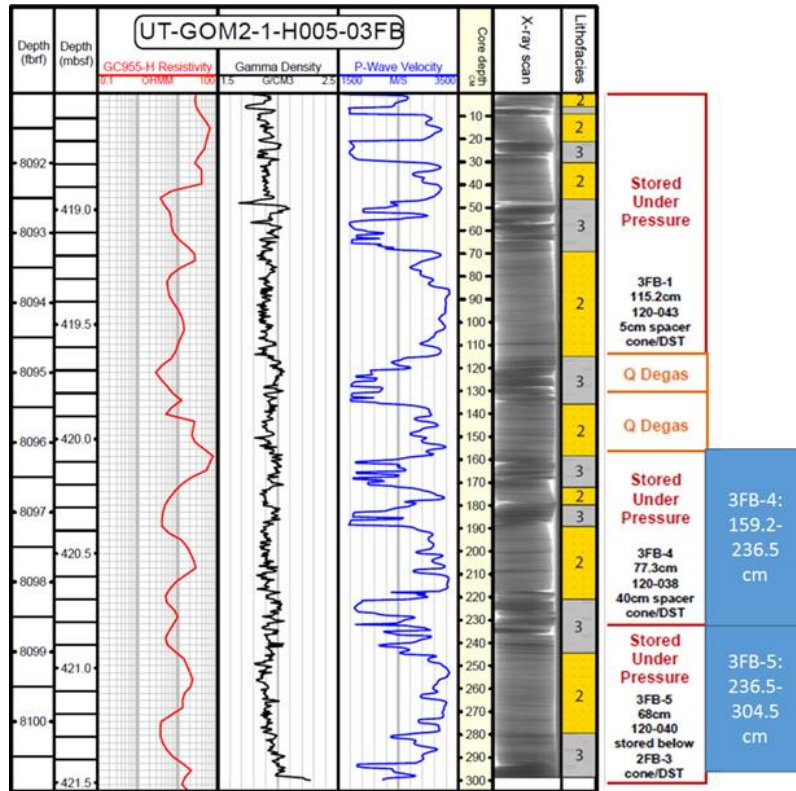
Boswell et al. 2012

UT-GOM2-1-H005-5FB



Expedition-1: Post Expedition Science

Pressure Core Characterization Tools (US); NETL Laboratories



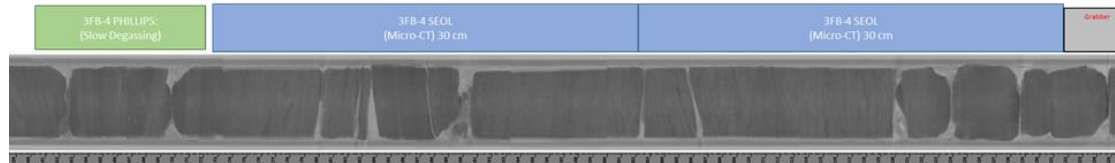
Full Characterization of Pressure Cores

- Index-level Properties: grain size, porosity, Sh
- Hydraulic-Mechanical Properties:
 - Consolidation, volume compressibility, Vertical/horizontal permeability, acoustic wave velocity, modulus, strength, water retention curve
- High Resolution Visualization of hydrate pore habits

Pressure Core Characterization Tools

- Retrieve, transfer, cut, subcore, and characterize naturally-occurring hydrate-bearing sediments at *in situ* P/T conditions

3FB-4



Pressure Core Characterization Tools

Transport
Chamber



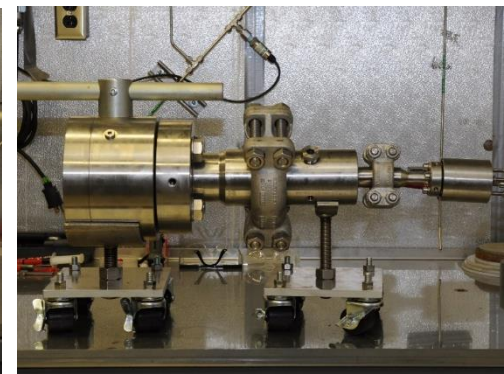
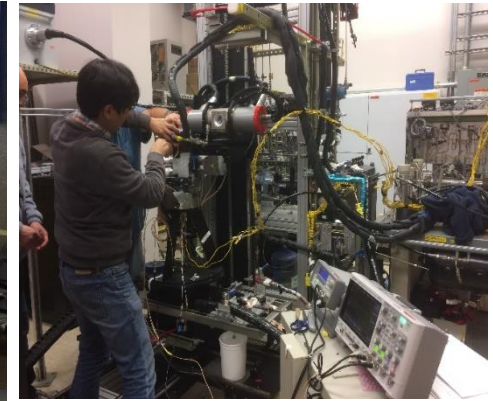
CT scanning
chamber



Sub-coring tool



Effective Stress
Chamber

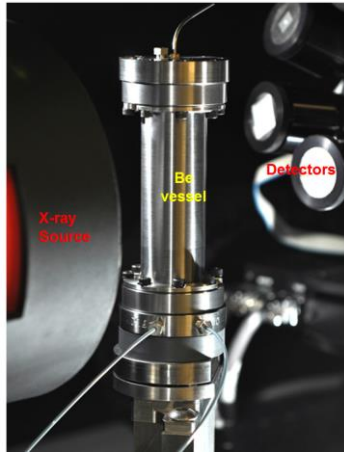


Sub-corer Transfer Assembly

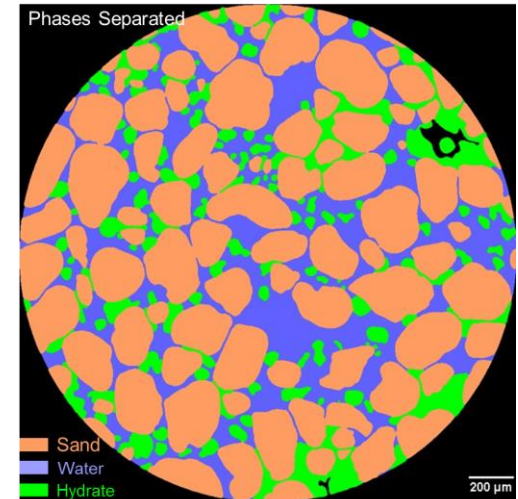


Visualization of Hydrate Pore Habit

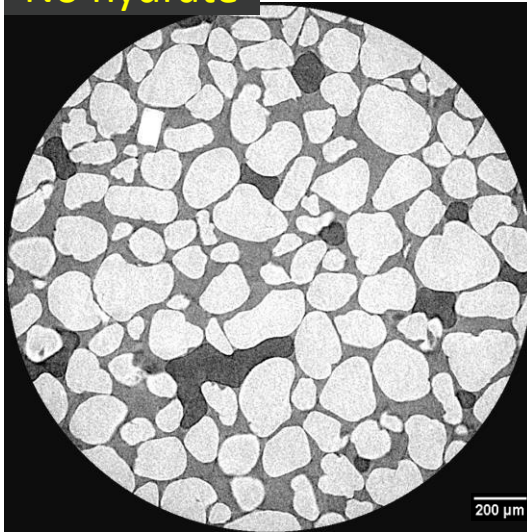
(a)



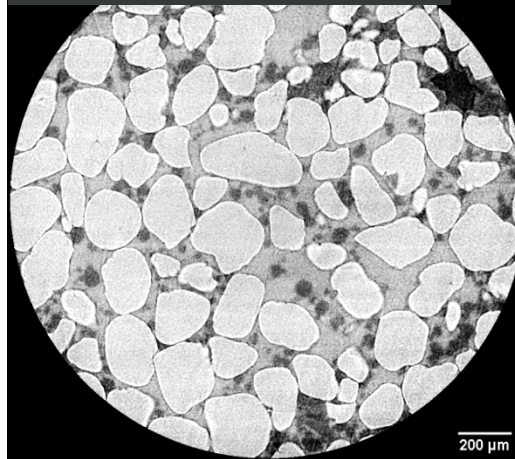
- Non-destructive CT imaging
- High resolution ($1\mu\text{m}$)
- Phase separation in 3D reconstructed images
- Further physical properties analyses



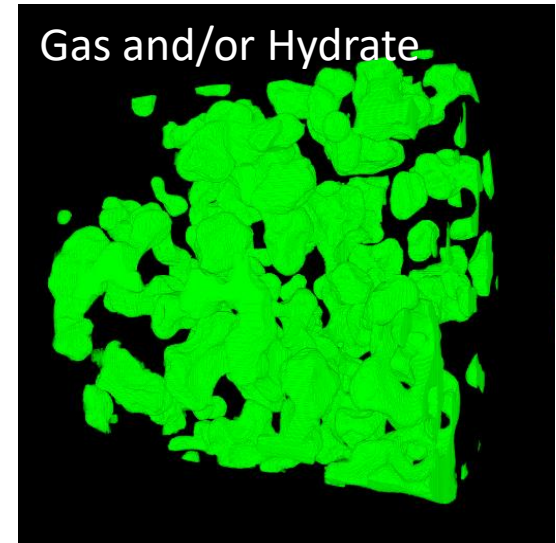
No hydrate



With hydrate
Pore fluid replaced



Gas and/or Hydrate



GOM² Expedition: UT Austin

Pressure-coring at known sites and exploration of high-value new sites

Expedition – 2 (2020)

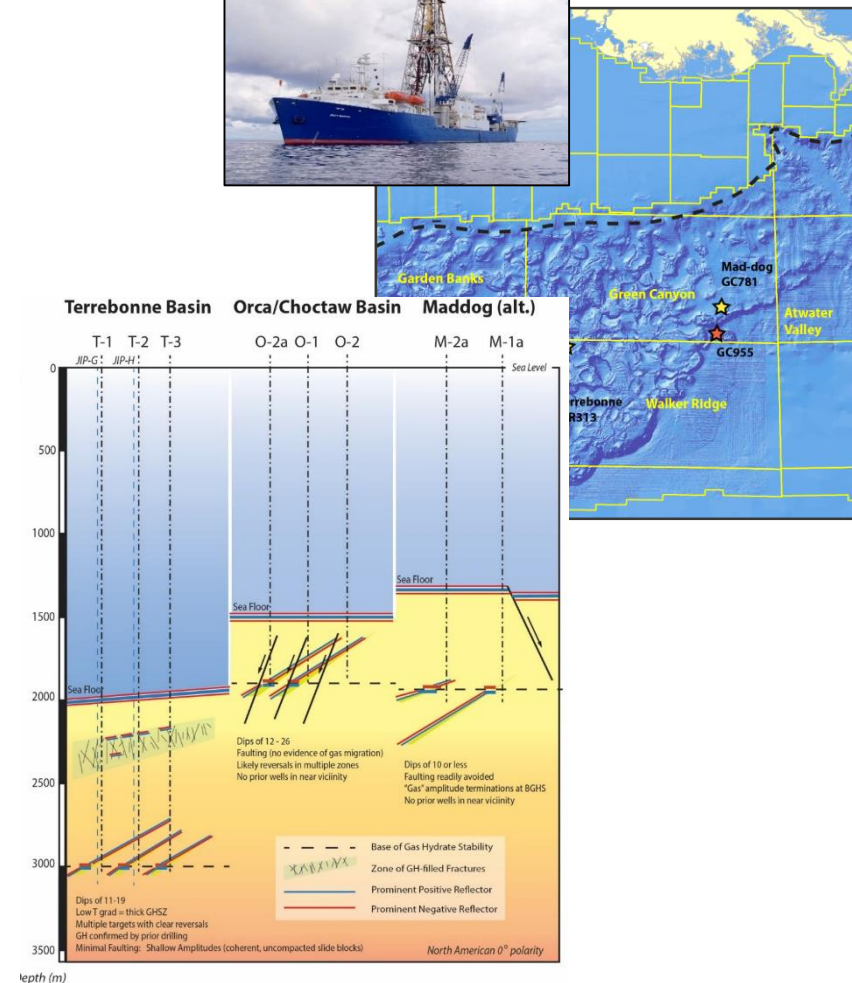
- Logging, MDT, and pressure coring at multiple sites.
- Scheduled for FY20 from *Joides Resolution* as IODP CPP 386 (approved by IODP May 2017), collaboration with IODP, TAMU, and the NSF.
- ~60 days of ship time
- Conducted within the IODP structure:
 - Access to world's premier scientific drilling vessel
 - IODP cost contribution, staffing, and liability coverage
 - IODP scientific and safety reviews/approvals

Core twins of 2009 JIP WR313 G&H Holes

- Gas and fluid chemistry; GH Habit; Microbiology
- Reservoir and Seal Petrophysics



Joides Resolution (Exp-2)



Alaska Long Term Production Test

Goals

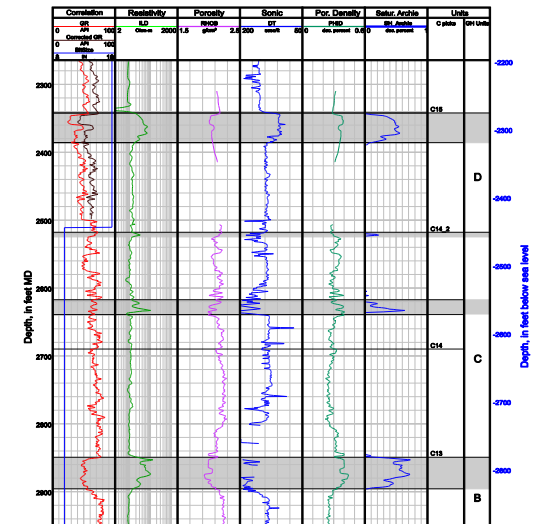
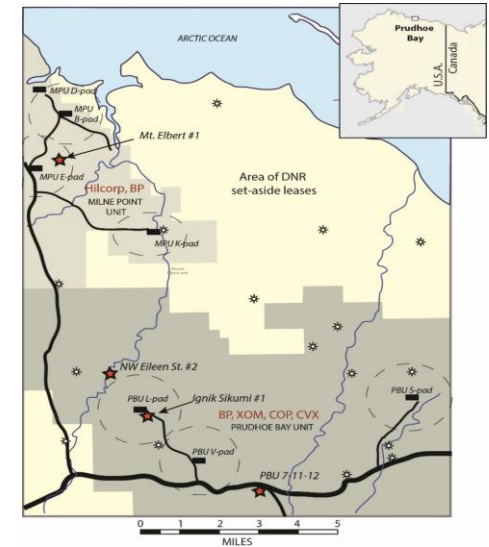
- Understand behavior of GH system in response to induced change over prolonged period (6 mo. Minimum)
- Evaluate technologies and approaches for initiating and maintaining flow

Alaska North Slope represents ideal test bed:

- Geologically well-characterized (complimented as needed by project strat/sci test wells)
- Hydraulic isolation (away from sources of free gas or water)
- Sufficient reservoir temperature (at least 5C) and intrinsic reservoir quality
- Multiple reservoir zones – operational risk mitigation and expanded science options
- Well location that allows continual operations of 6 mo (minimum); optimally 18-24 mo.
- Location that minimizes interference with ongoing operations
- Non-disruptive gas/water handling
- Minimal complexity – avoid use of unproven technologies

Key Test components

- Depressurization – pre-set or steady rates – enable scale to commercial
- Flow assurance - ability to maintain wellbore during likely interruptions
- Sand control
- Progressive well stimulation available – thermal, mechanical, chemical



Field Program Planning

Three Wells and Two Phase Program

- Phase 1: Conduct stratigraphic test and complete as monitoring well
- Phase 2: Establish facilities; drill & instrument science well; drill, complete and conduct test in production test well

Stratigraphic Test Well

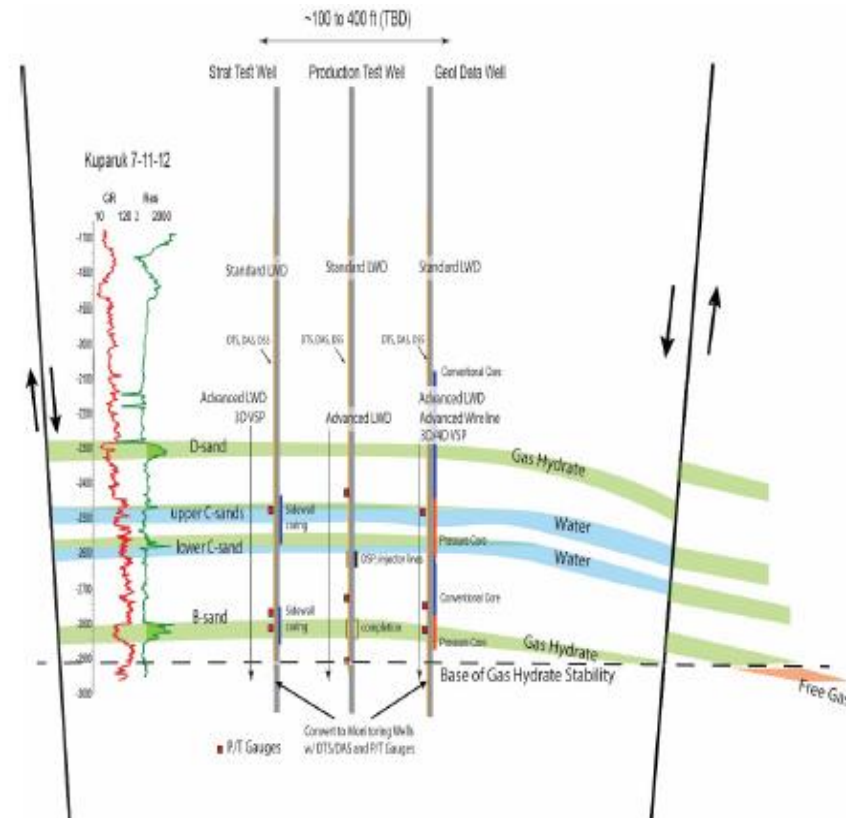
- To Confirm state of GH a Site
- To allow selection of test zone and finalization of science well and production well completion design
- Goal is fully saturated GH in B sand
- Fall-back is fully saturated D sand.

Geo-Data Well

- To acquire all geologic, engineering, petrophysical data needed to characterize the test reservoir and effectively interpret test results

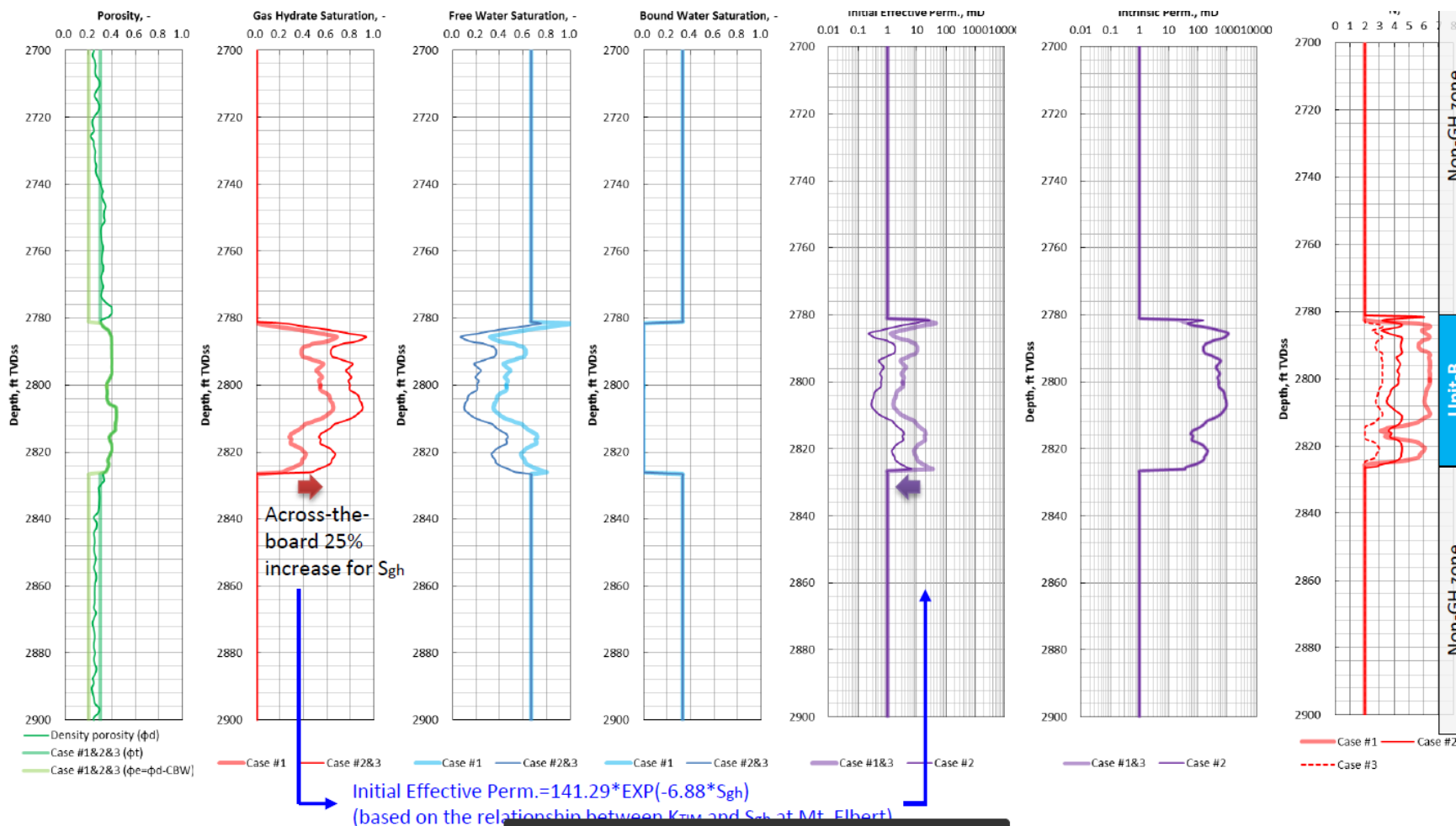
Production Test Well

- Completed for production and monitoring over extended period
- Sand control completion
- Well intervention pre-positioned



Geologic Input Models: B-sand

JOGMEC Simulation Input Summary

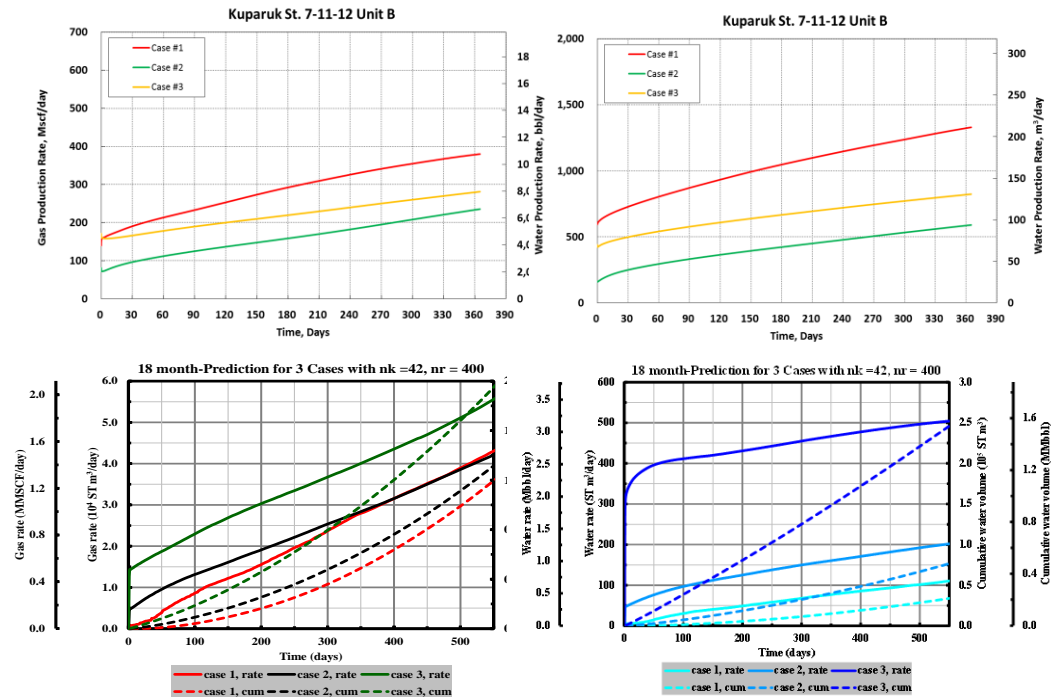


For further details of Case #1 (original model), see the JOGMEC Meeting on December, 16th 2015.
Filename: 151216_7-11-12 Reservoir Model Construction.pptx

Comparison Results: Gas Rate/Water Rate

Code Comparison:

- Difference on gas/water rate predictions.
- Comparing initial/boundary condition, mesh, relative permeability functions, thermal conductivity, pore compressibility
- Main gap maybe resulting from relative permeability functions (B&C vs. Masuda)
- No laboratory/field data to directly estimate parameters for relative permeability functions
- Progress on developing common conditions and parameter sets to share
- Agreed gas/water flow rates to be used for planning test design and operation



GAS RATE (mcf/d)	30 days	180 days	360 days
JOGMEC	100-200	160-290	220
NETL	50-600	450-1000	1000-1400
WATER RATE (bbl/d)	30 days	180 days	360 days
JOGMEC	250-750	450-1050	600-1350
NETL	54-2390	285-2683	502-2957

Code Comparison Study



- 5 Countries
- 21 Institutions
- 12 Codes

Code Comparison Study

- Objective of Code Comparison Study:
 - Check modeling concepts and approaches on newer hydrate reservoir simulators
 - Compare fundamental capabilities of codes, specific processes or models with properly designed problem sets
 - Share new ideas and approaches
 - Link experiments, field tests, and modeling
- New Focus on IGHCCS2
 - modeling **coupled** thermal, hydrological, and geomechanical processes and the effects on the production

Problem Set to be solved..



Hydrate Dissociation from
IGHCC1 Problems

Terzaghi's Problem with
Hydrate Dissociation

Nankai Trough Hydrate
Production

Coupled Geomechanics with
Radial Flow Problems



More to come.....

NETL R&IC Gas Hydrate R&D

- Enabling the realization of the Nation's methane hydrates resource potential, through:
 - Improved understanding of the **fundamental behavior of hydrates**, both *in situ*, and during man-made disturbances.
 - Development of **predictive modeling codes** that accurately describe gas production, responsive ground deformation, and environmental impacts.
 - **Laboratory characterizations** that support numerical simulations by providing accurate input data on physical properties of hydrate.

